The Debate About the Age of the Earth

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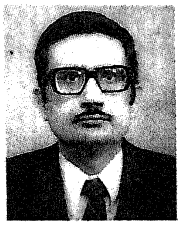

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Kelvin and the geologists argued about the age of the earth for nearly four decades. But the fate of Kelvin's view was sealed when the results of research on radioactivity became available at the beginning of the twentieth century.

Introduction

The age of the earth has been a topic for speculation throughout the inhabited world ever since human beings have inquired about nature and formulated cosmogonies. However, nearly all the events I describe here took place in the West against the backdrop of a Churchman's view, dating from 1654, that the earth was created about 6000 years ago.

Many schools of thought, such as, the Neptunist school of Werner, the Plutonist school of Hutton and the Catastrophist school of Cuvier, emerged with progress in the studies of minerals, rocks and fossils, as also of the earth as a whole, during the eighteenth and early nineteenth centuries. Eventually, the Plutonist school survived on the strength of its ideas, most notably the principle of uniformity, also known as the principle of uniformitarianism. They had a reasoned though qualitative view about the age of the earth. Parallel progress in physics brought out fundamental difficulties with some implications of the principle of uniformity. Alternate estimates of the age of the earth based on limited physical measurements and simplified mathematical analysis were not acceptable to most geologists. The stand-off continued for about forty years until a fresh new input showed that the geological view had greater merit.

Hutton, Lyell and Darwin

The Principle of Uniformity: James Hutton on the basis of extensive field observations and their analyses proposed in 1785 a whole new method of exploring geological phenomena. It was a watershed in the history of geology. The method was subsequently adopted and developed by Lyell. He made it the central theme of his *Principles of Geology*, first published in 1830. Whewell introduced the term Uniformitarianism in 1832 for this approach.

As Hutton put it, "*...Past history of the globe must be explained by what is happening now...*" In other words, geological processes and events from past periods of the earth's history can be reconstructed from a study of the rocks surviving from those periods and by observing how those or similar rocks undergo changes in our own time. A third, popular and catchy, rendition of the principle is that '*The present is the key to the past*'. This principle is called the principle of uniformity or the principle of uniformitarianism.

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The principle of uniformity assumes that the laws of physics and chemistry have remained constant throughout the history of the earth. It is the geological equivalent of the conjecture on constancy of the laws of nature through space and time. The principle affirms that geological phenomena can and should be explained in terms of natural causes exclusively.

Slow Rates, Feeble Forces and Long Durations: Hutton realised from his observations that geological processes act at exceedingly slow rates at present. He assumed that the rates were similarly slow in the past also. Hutton maintained that, even though many forces held responsible for geological processes appear to be feeble, when acting over long periods of time, they are capable of bringing about great transformations of the landscape. For example, consider the case of a stone slab under a tap. While a single drop falling on it may produce no perceptible effect, the succession of drops falling over the years produces a pronounced depression in the slab.

The Cyclical Nature of Geological Changes: Hutton asserted that geological processes operate in a systematic and cyclical manner. A group of processes called the processes of erosion slowly wear down the rocks exposed at the earth's surface. Erosion, as used here, includes the slow processes of weathering, or decay of rocks by fragmentation and or dissolution, as well as the removal of rock fragments and dissolved materials by agents of transportation. These materials most frequently end up on the ocean floor as loose sediments from which sedimentary rocks are formed through the slow processes of subsidence and consolidation. Molten rock material from deeper parts of the earth may intrude the shallower rocks and solidify there. Such rocks are called igneous rocks. Hutton suggested that granites form in this way. He also argued that existing rocks undergo changes in response to elevated temperatures and pressures leading to formation of metamorphic rocks. Hutton believed that the buried rocks experience upheavals in response to thermal expansion. Words Plutonism and the Plutonist school highlight all these speculations about the role of thermal processes in Hutton's formulation. Finally, the rocks brought to the earth's surface are exposed to processes of erosion again and the next cycle of geological changes begins. In other words, destruction of existing rocks in some part of the earth and formation of new ones elsewhere is a ceaseless, cyclic activity.

No Vestige of a Beginning: Hutton was convinced that the duration of the cycle just described is very long. He found in the rocks exposed on the surface evidence of a whole sequence of such cycles in the past. Thus he saw for the earth "*...no vestige of a beginning, no prospect of an end.*"

A Caveat: We have reproduced Hutton's ideas in some detail because of their bearing on the nineteenth century views about the age of the earth. Several of his ideas, most notably the mechanism of upheaval, have been modified as more evidence has come in.

The Evidence from the Fossil Record: Darwin read the first volume of Lyell's *Principles of Geology* in 1831–32 when he was a naturalist aboard the H M S Beagle during its five-year circumnavigation of the globe. Darwin was influenced profoundly. So, it is not surprising that the theory of evolution, expounded in his own 1859 book, *On the origin of species by means of natural selection*, has important similarities with the principle of uniformity. The most fundamental is that they seek to explain respectively the evidence of fossils and rocks through natural rather than divine causes.

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Fossils provide only a relative history of life on the earth. Nevertheless, Darwin was convinced that both the earth and the life on it were of great antiquity.

In Short: In short, the qualitative evidence of the rock and fossil records as interpreted by Hutton, Lyell and Darwin and their many followers, by about 1860, was that the earth has passed through long eons of time and thus it is very old.

The Labours by Kelvin

Kelvin (1824–1907) was a prolific scientist. He wrote more than 600 articles during his professional life. His contributions to the study of heat and thermodynamics are the most relevant here. Kelvin's first article, written at the age of 16, was on Fourier's theory of heat conduction. Kelvin espoused in 1847 Joule's principle of conservation of energy after a careful evaluation. Clausius in 1850 made it the basis of the first of his two laws of thermodynamics. Soon afterwards, in 1851, Kelvin put forward his own statement of the second law of thermodynamics. One of its many implications is that there can be no 'perpetual motion' machine. Kelvin also introduced the absolute scale of temperature. He returned to the theory of heat conduction around 1862.

Kelvin correctly looked upon the earth as a gigantic energy dissipating system. He was disturbed by the statements, such as, "*...no vestige of a beginning, no prospect of an end...*" and that the rates of geologic processes were the same in the past as they are today, because they implied to him that the earth was a perpetual motion machine with an endless supply of energy. Kelvin suggested that the earth began at a finite time in the past with a limited store of energy. He added that if the estimated age of the earth appeared too short to the geologists then they should entertain the possibility that the geological processes may have proceeded at faster rates in the past.

Kelvin estimated the age of the earth, in 1862, using the theory of heat conduction. He modeled the earth as a semi-infinite solid with a constant temperature T_0 in the interior and zero temperature at the bounding surface. He derived the following relation for the time t required to attain through cooling a temperature gradient G at the surface of the model.

$$t = (T_0 /G)^2/ (\pi \kappa).$$

Here κ is the thermal diffusivity of rocks. G is obtainable from observations of rise in temperature with depth in mines. With T_0=4000°C, G=30°C km^{-1} and $\kappa = 1.2 \times 10^{-6}$ m^{2}s^{-1} we get t in the range of 150 million years.

Keeping in mind the uncertainties in the values of the parameters involved, Kelvin suggested that the cooling of the earth could have lasted for not less than 20 million years and not more than 400 million years. His judgement, however, was that this duration was close to the lower end of the range. Kelvin also pointed out that these estimates were on the specific assumption that no sources of heat were present in the earth during that period. Kelvin also concluded from the analysis that, about one million year ago, surface temperature of the earth and the rates of geological processes should have been substantially higher than they are today. From 1862 onwards up to the end of the nineteenth century, Kelvin gave successively lower estimates for the upper limit of the age of the earth. By 1896, this estimate had come down to 24–25 million years.

Kelvin's stature was such that a few geologists tried to fit the history of geological events into the time frames provided by him. But most geologists did not agree with the results of those efforts and protested from the evidence of the rocks that Kelvin's estimates were unreasonably short.

The Showdown in 1899: Kelvin addressed the American Association for the Advancement of Science in 1899. He revisited the theme of the age of the earth in this address. He reiterated his views and defended his estimate.

Archibald Geiki responded, "*...the testimony of rocks emphatically denies Kelvin's inference that geological activities must have been more vigorous in the past than they are today.*"

Chamberlin's Rebuttal: Chamberlin wrote in the same year a point by point rebuttal of Kelvin's address. Primarily a geologist, Chamberlin too was a man of many parts. For example, in later years, he worked with Moulton, the astronomer, to revive and modify Buffon's collision hypothesis about the origin of the solar system. But, in 1899, he was eminently the geologist best prepared to mount a deadly attack on those parts of Kelvin's analyses that rested on the idea of a uniformly cooling earth.

Chamberlin had spent a large part of his professional life up to that time in geologic fieldwork in Wisconsin and neighbouring regions of USA and Canada where there is abundant evidence of past glaciations. Geologists infer that within the last 2 million years or so there have been at least four major periods of glaciation whose effects were felt in northern parts of North America, Europe and Asia. Proceeding backward in time, they have been

Box 1.

Most of us are amazed at the powers of mathematics. The occasional article with a title such as '*The Unreasonable Success of Mathematics*' adds to our awe and wonder, but it does not solve the mystery. The rare critical view, if expressed with due consideration, is sobering and a useful corrective.

Hubbert quotes from Chamberlin's response to Kelvin in 1899 as follows. "*There is, perhaps, no beguilement more insidious and dangerous than an elaborate and elegant mathematical process built upon unfortified premises.*" This is clearly not a diatribe against mathematics or mathematicians. Rather, if anything, it is a comment on how some users of mathematics brandish the results. Those of us who use mathematics in our diverse fields might heed it as a cautionary remark. Mathematics is a powerful tool that should be used with care and circumspection.

named as the Wisconsin, Illinoian, Kansan and Nebraskan glaciations. The Wisconsin glaciation ended about 11000 years ago. Although the glaciers of this age did not reach as far south as the Himalaya, as a result of the global cooling during the period, the snow cover must have been substantially greater and the snow line lower than they are today. The rocks around the globe, including those in India, also contain evidence of numerous continental scale advances of ice in still earlier geologic periods.

Chamberlin argued that if the earth were to cool in the monotonic manner envisaged by Kelvin, then there could be only one terminal glaciation in the history of the earth. The record of repeated glaciations available in the rocks indicates that Kelvin's analysis based on theory of heat conduction without internal heat sources is untenable and the estimates of the age of the earth based on it are erroneous.

As to what those heat sources might be, Chamberlin remarked prophetically that "*...there might yet be discovered new sources of energy within the particles of matter...*" We may recall that the phenomenon of radioactivity had been discovered already, but the fact that it is a potent source of heat had not been established by 1899.

Heat from Radioactivity: Rutherford and Soddy estimated in 1903 the amount of heat generated during radioactive disintegrations. Rayleigh, in 1906, detected the presence of minute quantities of the radioactive elements in common rocks from all parts of the world. It dawned that the rocks of the earth's crust contain within them an unfailing source of heat. Since the temperature at the earth's surface is not changing today, the energy lost due to radiation into space and in various energy dissipative geological processes is made up by radioactive heat generation in the crust.

Age of the earth can be deduced from the rates of radioactive disintegrations. Rutherford pointed out, in 1904, the potential usefulness of radioactive elements and their daughter products in dating earth materials. Rayleigh obtained in 1906 an age of 2 billion years for the earth based on helium content of radium bearing rocks. The estimate has been revised upward with the passage of time. This came about as the initial techniques of radioactive dating were cross-checked and improved where necessary. Also new techniques, such as those utilising the mass spectrograph, became available with progress in physics. An estimate of 4.6 billion years for the age of the earth is accepted widely today.

Discussion

No real Winners or Losers in the Debate: A sane view of the debate about the age of the earth is that there were no out and out winners or losers. Kelvin, to be fair, did point out in 1862 that his analysis was based on the assumption of no heat generation in the earth. His declamation in this regard was for the sake of rigour in stating the mathematical problem to be solved rather than on the basis of any specific evidence on the issue. He erred only in that he did not take a cautious view of his calculations because of this assumption. Rayleigh's estimate of 2 billion years for the age of the earth was available before Kelvin passed away in 1907. If alive today, he would have derived satisfaction from the fact that geologists have adopted the principles of thermodynamics whole-heartedly.

At the same time, Hubbert has argued that the geological evidence available to Hutton and his followers most abundantly was from rocks of the past 600 million years or so. This span of time is only about a seventh of the currently estimated age of the earth. An equilibrium should have been attained between heat generation and dissipation within the earth by this time. Thus, it should be safe to assume that the rates of geological processes in this period of earth's history were comparable to the rates today.

The Two Geological Methods of Estimating Absolute Age: Eventually, geologists did come up with two methods of their own for estimating absolute ages. In one of them, they sought the ratio of the total thickness of sedimentary rocks ever deposited

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in the oceans and the current rate of sedimentation on the ocean floor. This would provide a rough lower limit on the age of the earth. In the other method, geologists sought the ratio of the total amount of sodium in the oceans and the amount of sodium carried annually by the rivers of today. This would give an estimate of the age of the oceans. It was evident from the beginning that the results of these methods would be uncertain because of the scope for error at every step. The methods have only historical significance today because the radioactive methods of dating are so much more accurate and convenient.

Holmes and the Puranic Estimate: Holmes was a young student when he joined Rayleigh to learn about the radioactive methods of dating rocks. He wrote a series of articles on the subject between 1911 and 1966. Holmes was fond of quoting from the Vishnu Purana. Apparently, according to this Purana, the year 1998 AD should be the year 1,972,949,099 since the present world came into being. Two coincidences related to this date are notable. First, recall again that Rayleigh's initial estimate of the age of the earth based on radioactivity was about 2 billion years. Second, new millennia will be starting within one year of each other by the Gregorian calendar and the Puranic reckoning.

Parting Thought: The quest for the age of the earth has been a purely intellectual pursuit. The practical spin-offs of this activity have been many and, with a little thought, they are easy to see. Student readers of this article are encouraged to think about them so that they get further evidence on the need for basic research without always thinking about immediate returns on the cost and effort incurred.

Suggested Reading

[1] M King Hubbert, Critique of the Principle of Uniformity, In: C C Albritton Jr., (Ed), *Uniformity and Simplicity* (GSA special paper 89, pp. 3–33). The Geological Society of America, Denver 1967. Also reprinted in: Preston Cloud (Ed). *Adventures in Earth History*; W H Freeman and Company, San Francisco, 1970.

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